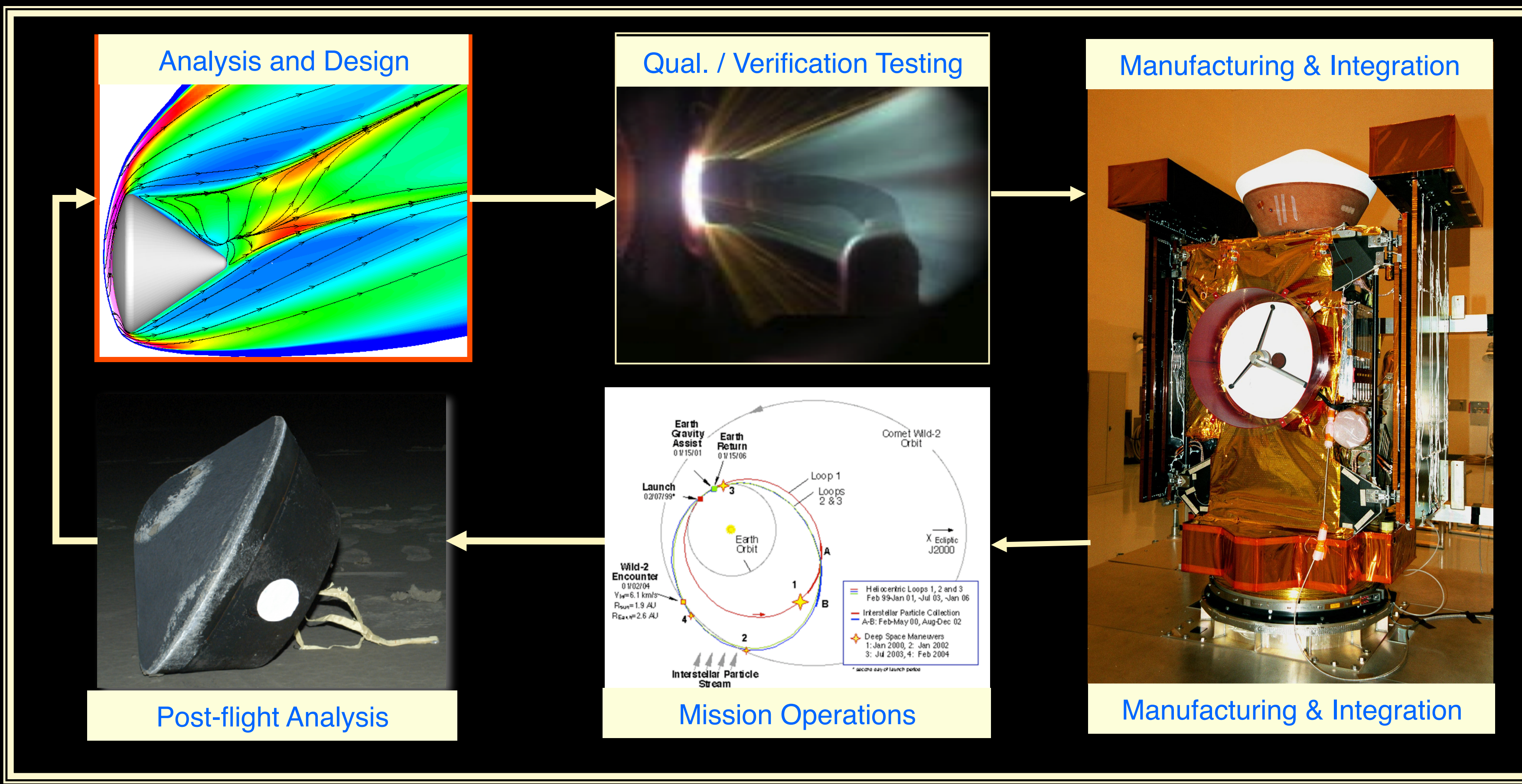
Challenges and Strategies for Sustaining TPS/Entry Technology in the Era of Focused Projects and Programs



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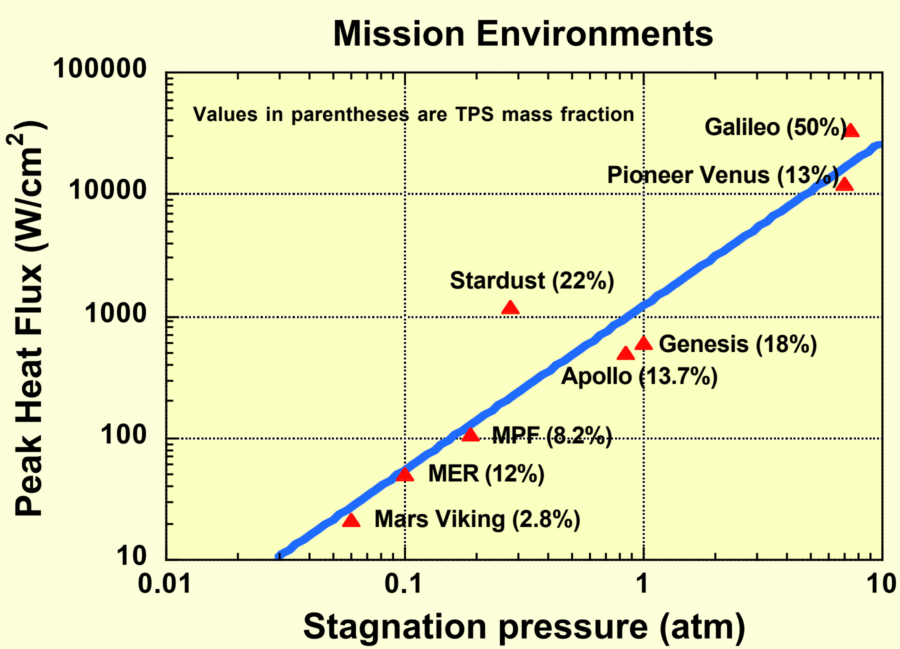
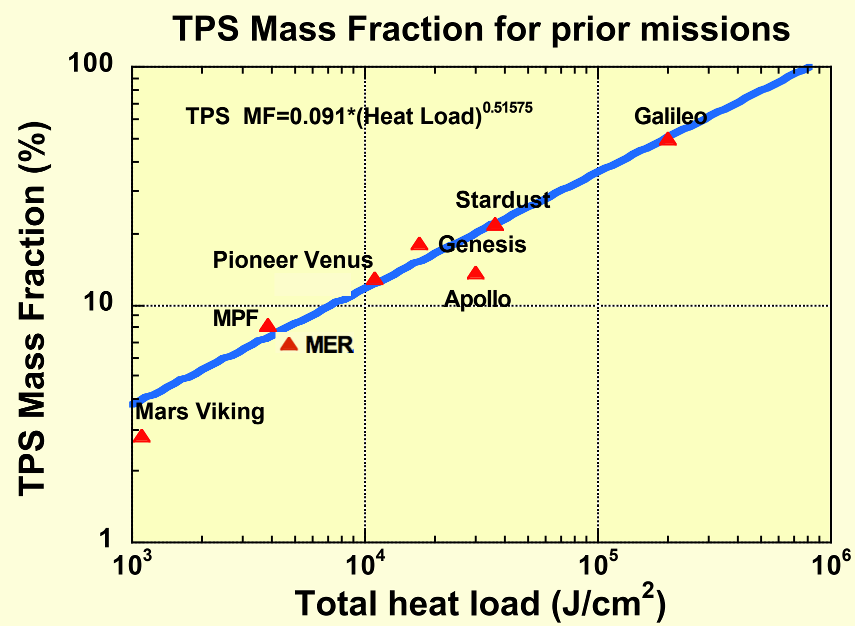
Background: TPS / Entry Technology

♦ Should we worry about TPS/Entry Technology?

- NASA entry probes have successfully survived entry environments ranging from the very mild (Mars Viking ~25 W/cm² and 0.05 atm) to the extreme (Galileo ~30,000 W/cm² and 7 atm)





Can we sustain the capabilities?
Will we be able to improve it?

Motivation

- **TPS/Entry Technology base:**
  - **Capabilities**
    - Analytical, experimental, design and manufacturing
  - **Verification facilities**
    - Hypersonic/hypervelocity tunnels,shock tubes, arc jets, large scale thermal-vac and vibro-acoustic facilities, etc.
  - **Experts (& expertise)**
    - Analytical, experimental, design, manufacturing, flight and project
- **Apollo era vs. to-day**
  - Far fewer experts, lot fewer facilities
  - Despite computational capabilities, lack of test facilities/data limit our ability to perform simulation/design with high confidence
- **Where do we need to be in the next 2 decades and what do we need to do?**
  - Human exploration of Moon
  - Robotic and precursor missions leading to human exploration of Mars
  - Robotic Solar System exploration

Outline

- Background and Motivation
- **Technology Needs and Strategies: Past**
  - Golden Era: 1960 - 1975
  - Shuttle Era: 1970 - 1980
  - Goldin Era: 1990s
- **Technology Needs : Present & Future**
  - Human: CEV (LEO, lunar)
  - MSL
  - Human: Mars
  - Robotic: Venus, Saturn, Neptune, Jupiter
- **Strategies Recommended**

TPS /Entry Technology
Golden Era (early 60 - mid 70)

♦ Missions and TPS Technology

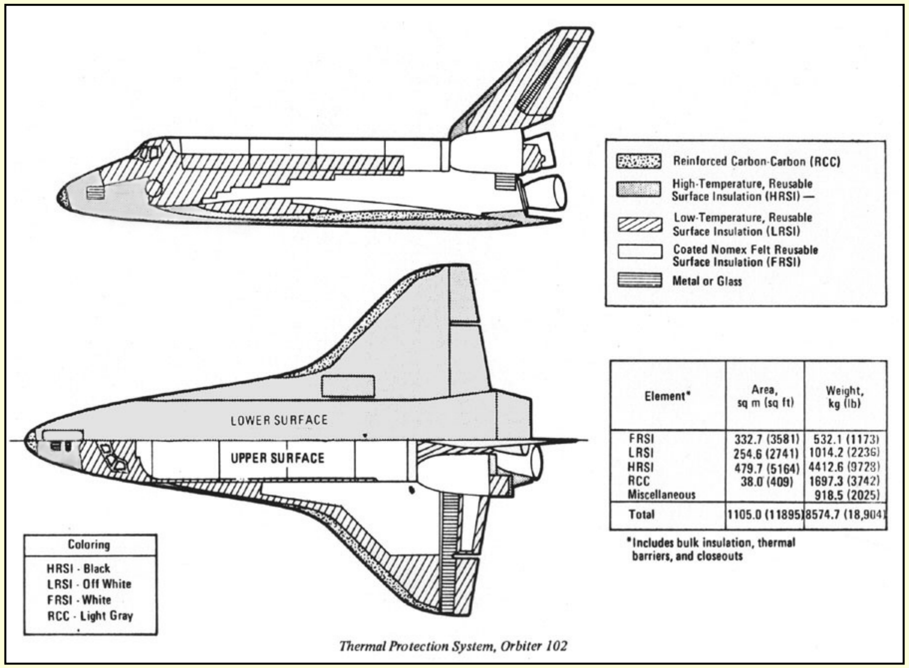
• Moon:	Apollo	1961 - 1975	Avcoat 5026-39/HC-G
• Mars:	Viking	1976	SLA-561V
• Venus:	Pioneer-Venus	1978	Carbon-Phenolic
• Jupiter:	Galileo	(1995)	Carbon-Phenolic

Strategy Employed:

- Budget not a constraint
- Leveraged early DoD investments from ballistic missile programs and modified it to NASA Missions for ablative TPS
  - Carbon - Phenolic heritage directly attributable to DoD investments
    - Tape Wrapped & Chop Molded
    - Heritage Rayon
- Apollo HS AVCOAT development
  - SLA technology leveraged Apollo HS technology - Honeycomb filled with resin
- Test, test and test to verify
  - Approximately 20 arc jets around the country
    - Giant Planet Facility specifically built for Galileo is an example
    - Combined radiative-convective arc jet facility in support of Apollo

TPS /Entry Technology
Shuttle Era: 1970 - 1980

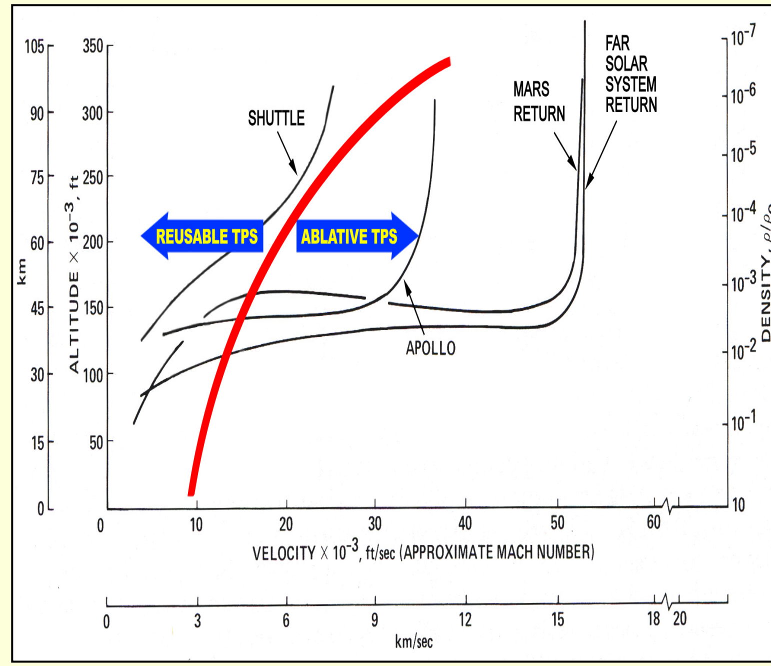
Reusable TPS: Tiles/Blankets



Element*	Area, sq m (sq ft)	Weight, kg (lb)
FRSI	332.7 (3581)	532.1 (1173)
LRSI	254.6 (2741)	1014.2 (2236)
HRSI	479.7 (5164)	4412.6 (9728)
RCC	38.0 (409)	1697.3 (3742)
Miscellaneous		918.5 (2025)
Total	1105.0 (11895)	8574.7 (18,904)

*Includes bulk insulation, thermal barriers, and closeouts

Thermal Protection System, Orbiter 102



Strategy Employed: Focus on reusable TPS Technology for Shuttle Mission

Impact: From the mid-70's to the late 90's ablator TPS technology lost focus, expertise resulting in reduced national capabilities.

TPS /Entry Technology (Dan) Goldin Era:1990s

- **Mars: SLA 561 V**
  - Mars Pathfinder (106 W/cm^2, 2.65 m)
  - Mars Polar Lander / DS-II (~100 W/cm^2, 2.4 m)
  - Mars Exploration Rover (44 W/cm^2, 2.65 m)
  - Phoenix* (65 W/cm^2, 2.65 m)
  - MSL* (155 W/cm^2, 4.6 m)

Strategy: leverage heritage and stick with what works

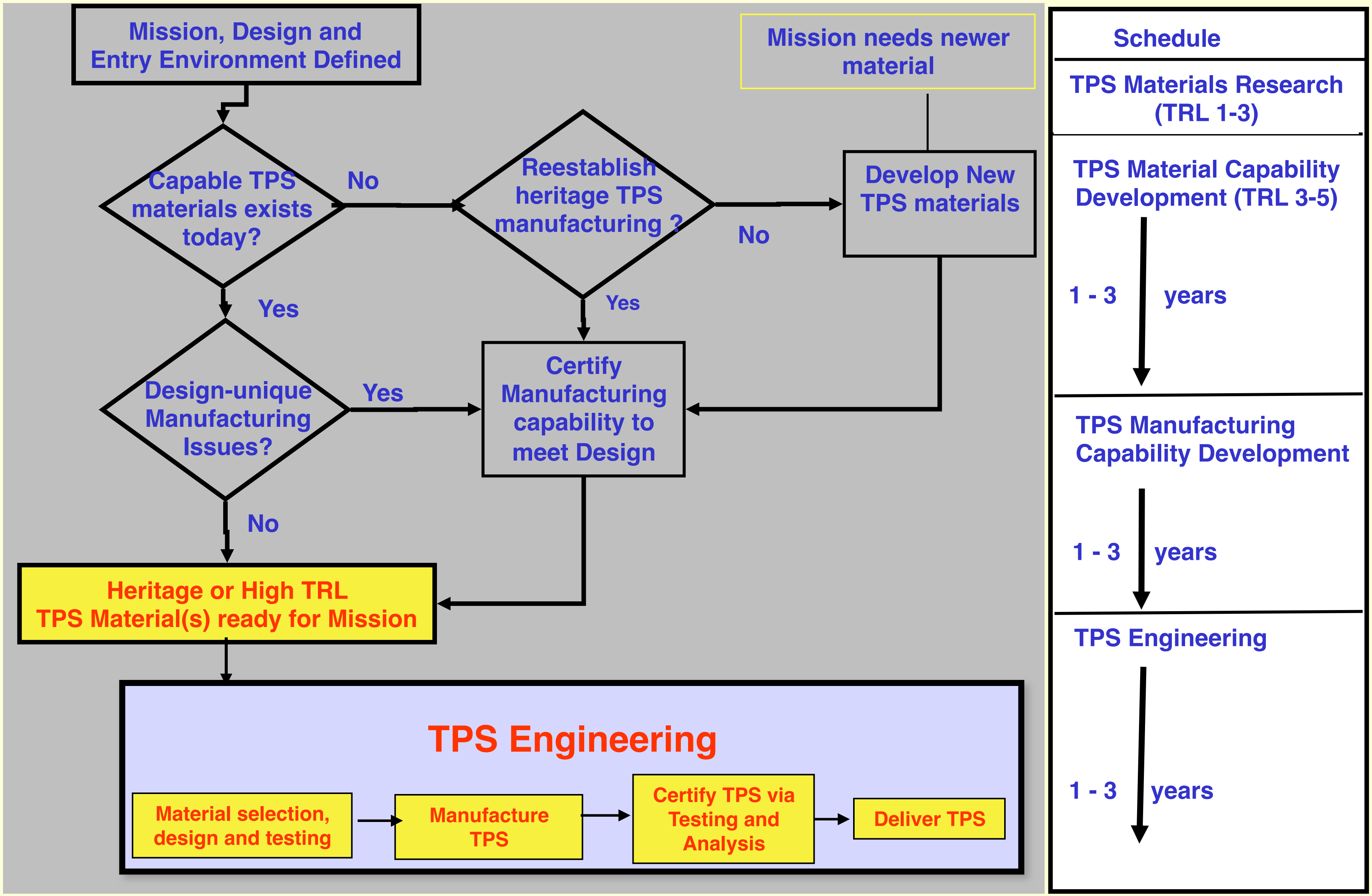
- **Sample Return: PICA, ACC (Strategy: faster, better, cheaper)**
  - Stardust (1200 W/cm^2, 0.83 m)
  - Genesis (700 W/cm^2, 1.51 m)

Strategy: Accept the risk / Faster, better, cheaper

- **Titan: AQ60**
  - Huygens (~200 W/cm^2 , 2.7 m)

* Planned missions

TPS Materials Technology Development and Engineering Timeline

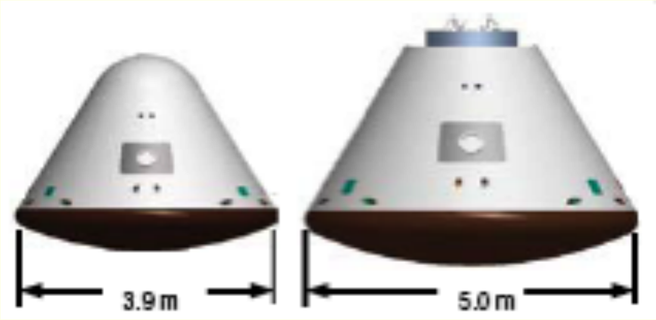


Lunar Exploration Strategy: CEV TPS Advanced Development Project

- **TPS ADP Main Goal: Develop a single heat shield, capable of both lunar & LEO missions**

	Velocity, km/s	Heat Flux, W/cm^2	Heat Load, kJ/cm^2
Lunar	**11.0**	**~1000**	**~ 100**
LEO	**8.0**	**~ 175**	**~50**

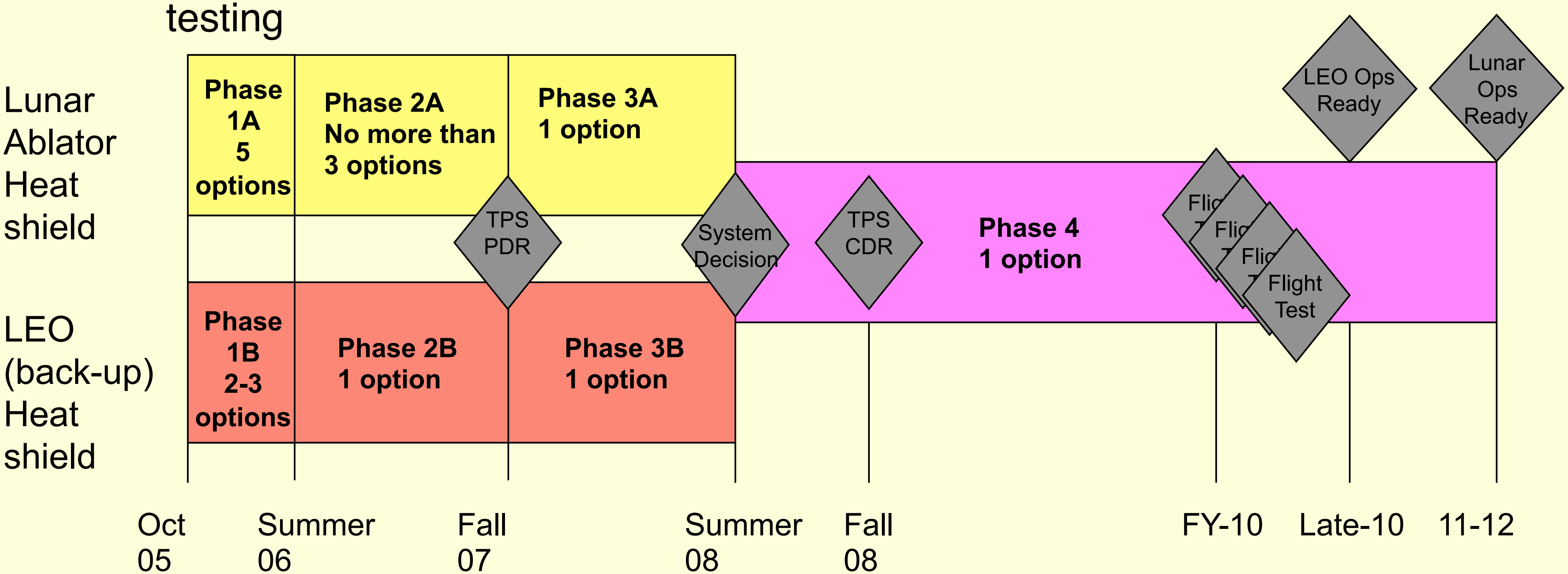
- **Challenge: largest diameter lunar-capable heatshield ever (CEV is not Apollo)**
  - Apollo heritage TPS Avcoat is not TRL 9 because material went out of production
  - CEV aerothermal environments are more severe (radiation)
  - Increased scale of CEV presents unique heat shield performance risks for both uni-piece and multi-piece manufacture



Apollo **CEV**

CEV TPS Development Strategy (Critical Path Item)

- **Heat-shield TPS for lunar return environment by → 2011-2012**
- **CEV application beginning in 2010 for LEO return**
  - Parallel development of human-rated, scaleable LEO return solution as back-up/off-ramp maintained through Summer-08
  - Backshell TPS using Shuttle materials
  - Flight test program beginning in 2010 to validate analysis and ground-based testing



Lunar Return Heat Shield Driver: Manufacturability than Material Performance

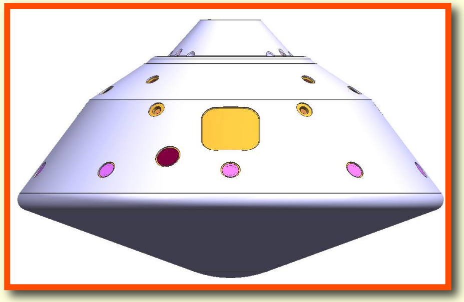
- Several TPS material choices currently exist with adequate lunar return performance characteristics
- The candidate options require different manufacturing processes
  - **Monolithic, homogeneous/ part** – large contiguous single-piece panel
    - **Example: Carbon-Carbon**
  - **Monolithic, filled honeycomb cells** – just like Apollo or with larger cells
    - **Example: Avcoat**
  - **Segmented – large panels** (~ 1m x 1m) with seams and/or gaps, possible overlaps (shingled approach) or bonding between panels
    - **Example: PICA**
  - **Tiled – Shuttle sized TPS tiles** (~0.3m x 0.3m) with gaps

Approach: Combine analysis and test results with an assessment of manufacturing, repair, and operability risks in down selecting the TPS

Heat-Shield Manufacturability and Performance Challenges

- Manufacturability: **Can any of the manufacturing approaches succeed in creating a heatshield of ~5.0 m diameter?**
  - **Monolithic, homogeneous part**
    - Can such a large single piece part be fabricated?
    - Can such a single piece ablator part be integrated with the carrier structure with provable bond integrity?
  - **Monolithic, filled honeycomb cells**
    - Reviving and reestablishing Apollo era technology
    - From a cost and/or schedule perspective is a ~5 m heatshield feasible?
  - **Segmented – large panels**
    - Can such segments be either bonded together (hardened seams) or overlapped to prevent possible gap heating?
    - How can the segments be bonded to the carrier structure with provable integrity?
  - **Tiled**
    - Can a tiled solution be created with provable tile bond integrity and gap performance?
    - Can a complete heatshield be fabricated with allowable gap tolerances or gap fillers?

Robotic Mars and Human LEO TPS/Entry Technology
MSL and CEV Similarities

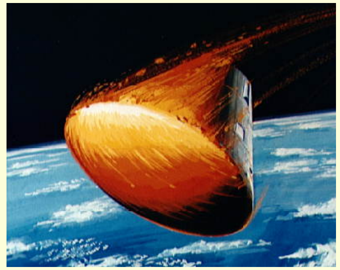


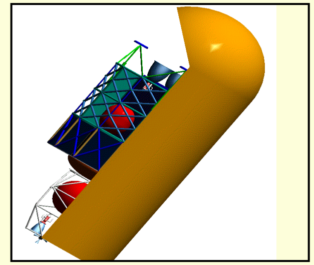
Parameter	MSL	CEV ISS
Shape	Blunt 70° cone	Apollo
Diameter	4.5 m	5.0 m
Max heating rate (w/margin)	160 W/cm^2	167 W/cm^2
Max heat load (w/margin)	5.5 kJ/cm^2	40 kJ/cm^2
Max pressure	30 kPa	54 kPa
Max shear	325 Pa	250 Pa
Forebody penetrations	None	6
Ejectable forebody H/S	Yes	Yes
Entry	Lifting	Lifting

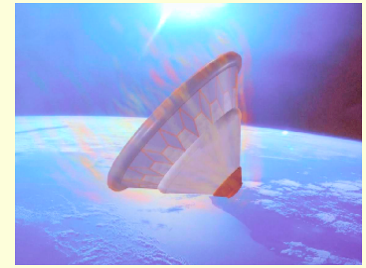
Opportunity to collaborate and reduce development risk
for both MSL and CEV

Beyond 2020: Human Mars Exploration
Mars Entry and Earth Return Challenges


Ballutes


Rigid Aeroshell


Ellipse-Sled


Hyper-Cones

	Candidate Mission Scenario	Candidate Capabilities
Mars Entry	♦ Mars cargo aerocapture ♦ Mars cargo aerocapture followed by Entry ♦ Mars human and cargo aerocapture followed by Entry	♦ Rigid Aeroshell ♦ Flexible /Deployables ♦ <u>Combination</u>
Earth Return (Mars)	♦ Direct Entry ♦ Entry with skip-out ♦ Aerocapture followed by Entry	♦ <u>Rigid Aeroshell</u> ♦ Flexible/ Deployables ♦ Combination
Earth Return (Lunar)	♦ Direct Entry ♦ Entry with skip-out ♦ Aerocapture followed by Entry	♦ <u>Rigid Aeroshell</u> ♦ Flexible / Deployables ♦ Combination

Current technology cannot land ~70 metric tons at Mars' surface, as required for human exploration. Technology development needed if we are to send humans to Mars.

Future Planetary Robotic Missions: Venus, Saturn & other Destinations

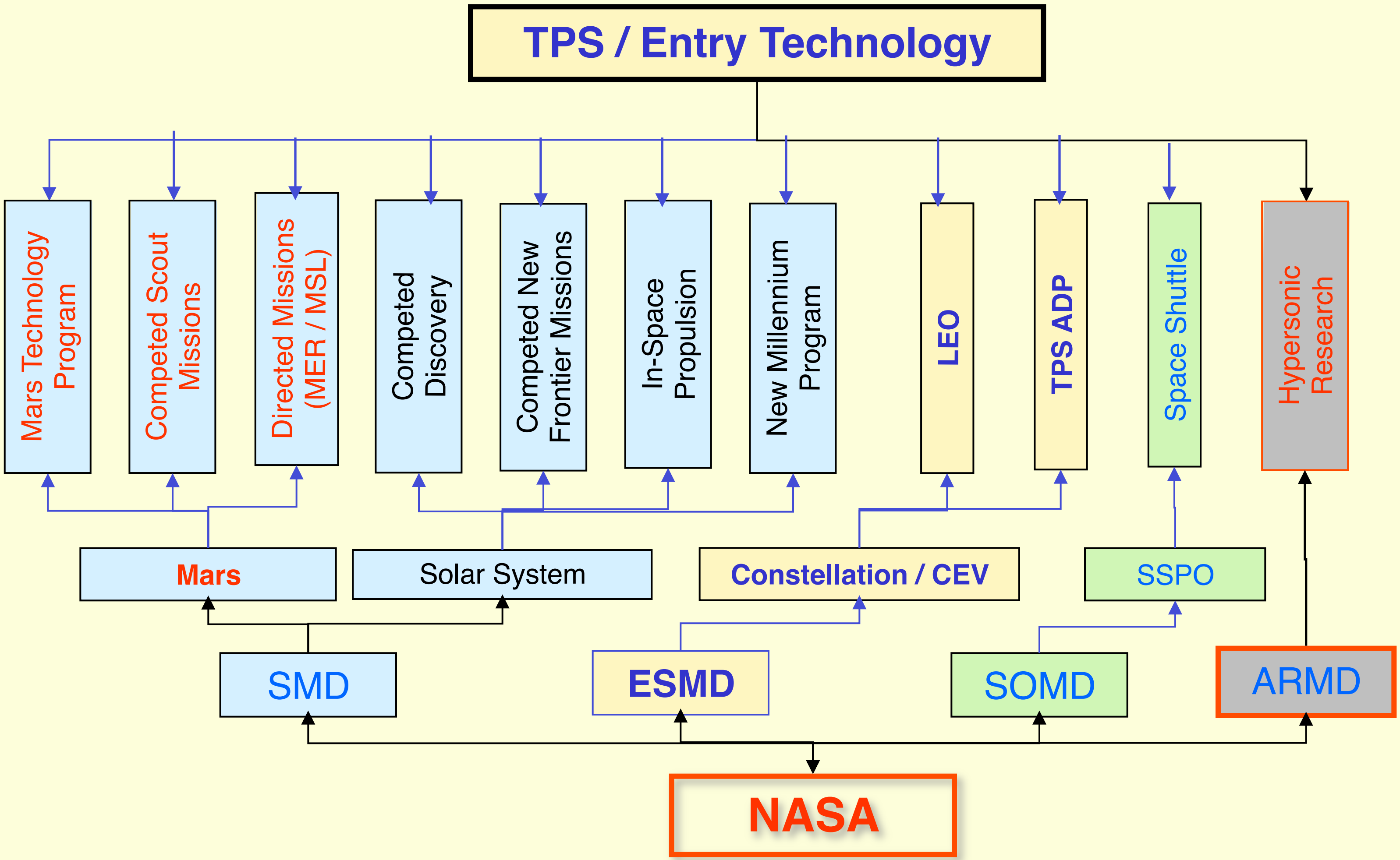
Future Needs

Without a TPS/Entry Technology strategy, key future missions are at risk

Example: New Frontier Jupiter multi-Probe Mission was not feasible due to lack of TPS capabilities

- **Viable TPS alternate for heritage Carbon-Phenolic**
  - Venus, Saturn, Jupiter, Neptune and high energy sample return missions
- **Valid modeling and analysis tools**
  - Coupled radiation, ablation and flow physics needs improvement
  - Material response models
- **Facilities**
  - Current arc jet facilities have limited test capability
- **Manufacturing and Test Capabilities**
  - Limited by size or capability
- **Expertise**
  - Limited to very few centers and personnel
  - retired/retiring or **vanishing**

NASA's TPS/Entry Technology Stakeholders: Organizations, Programs and Projects



Technology development limited by funding stream and organizational structure

Strategies

- **Challenge Key Organizations & Managers to maintain/develop experts and expertise**
  - Maintaining and (re)building the expertise
  - Recruiting and training the workforce for the future
  - Encourage / Fund Universities to offer TPS Technology
  - Engage Students and young faculty in TPS Technology
- **Maintain & improve Critical Facilities**
  - Shared responsibility - support, maintain and upgrade
- **Evolve an integrated investment strategy**
  - TPS/Entry technology benefits multiple missions/projects/programs
  - Coordinate investment in TPS Technology to benefit beyond a single mission or destination
    - ISP is a good example
- **Develop a long term technology strategy for**
  - Mars Human Exploration and Sample Return
  - Neptune Orbiter, Jupiter Deep Probe
- **Invest in sustained & strategic advanced/applied research**
  - PICA and SIRCA are two examples

“The Times They Are A Changin’ ”

By Bob Dylan

Come gather 'round people
Wherever you roam
And admit that the waters
Around you have grown
And accept it that soon
You'll be drenched to the bone.
If your time to you
Is worth savin'
Then you better start swimmin'
Or you'll sink like a stone
For the times they are a-changin'